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Evaluation of the Head Injury Hazard During Military Parachuting

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The incidence of head injury during U.S. Army airborne training and airborne operations has doubled in recent years. A number of factors are known to contribute to head injuries incurred during airborne training/operations. These factors include the small amount of impact protection provided by the PASGT helmet, shortcomings in training procedures, and failure of trained airborne troops to follow proper procedures when jumping. Other factors are involved as well. This report shows, with relatively little modification, the impact protection and retention characteristics of the PASGT airborne helmet can be significantly improved. Also, this report evaluates a number of factors present in airborne training and operational environments that contribute to head injury and explains how training and operational procedures can be modified to reduce the incidence of repeated headstrikes and subsequent serious head injuries.

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Introduction

The incidence of head injury in U.S. Army airborne training and operations has increased twofold in recent years (Sadlowski, 1990), but the problem of head injury in military parachuting dates back to World War II (Essex-Lopresti, 1946). Repeated head strikes have been a significant cause of head injury in airborne operations since the early days of military parachuting (Kiel, 1965). Repeated sublethal head strikes may have cumulative injurious effects on the brain. These effects are insidious in that the victim often can suffer a number of head strikes without any loss of consciousness or serious neurological deficit. However, later, the victim can experience sudden unconsciousness or, occasionally, death. As recently as August 1989, this problem was noted in the investigation of a swing landing trainer incident at the Airborne Training School at Fort Benning, Georgia.

In response to this problem, the U.S. Army Infantry School (USAIS) at Fort Benning, Georgia, tasked the U.S. Army Aeromedical Research Laboratory (USAARL) to evaluate factors in airborne training and operational environments that contribute to head injury and to recommend changes that will reduce head injuries (USAIS, 19 Oct 89). The objectives of this report are: (1) To determine the incidence of head injury in airborne training and operations, (2) to determine if the personnel armor system for ground troops (PASGT) helmet can be modified to provide more impact protection and retention stability for airborne troops, and (3) to assess factors present in airborne training and operational environments that contribute to head injury.

Background

The M-1 infantry helmet was adopted by the U.S. Army in 1941 and was used by both ground and airborne soldiers. In the late 1960s, the airborne community requested the development of additional head strike protection. This was in response to six fatal head injuries during a 5-year period that were attributed solely to a blow to the back of the head (Coston, 1974). In 1969, the Airborne Department of the USAIS began issuing shock-absorbing pads cut in bulk quantity from 1/2-inch thick Ensolite™ foam*. These pads were mounted in the rear of the M-1 helmet. In December 1972, Natick Laboratories met with USAIS to find a better solution to the M-1 helmet head injury problem. In February 1974, the U.S. Army Test and Development Command (TECOM) published its final report on the M-1 helmet shock-absorbing pad.

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* See list of manufacturers

The initial prototype pad had been disposable. A long-term, easily installed prototype pad was recommended in lieu of the disposable pad (Coston, 1974).

The PASGT infantry helmet was developed in the 1970s. This helmet offered greater ballistic protection, stability, and comfort compared to the M-1 (McManus, Durand, and Claus, 1976). The PASGT helmet is a rigid, close-fitting helmet with a cradle-type suspension system. When struck by a 17-grain mass fragment, it provides 2000 fps protection compared to the 1100 fps protection of the M-1 helmet. In June 1977, USAARL evaluated the PASGT helmet for airborne operations. USAARL recommended the use of the PASGT by airborne troops with the stipulation that the helmet have a stronger modified chinstrap and an energy-absorbing nape pad (Allemond and Current, 1977). Final evaluation of the modified paratrooper PASGT helmet was completed in 1978 (Morimoto, Bishop and Dence, 1978).

At the request of the Commander, Natick Research and Development Command (Natick Research and Development Command, February 1979), USAARL evaluated the airborne PASGT retention system. Weaknesses were noted, and a suggested modification to the retention system was recommended, but there was no recommendation to delay the safety release. The current PASGT airborne helmet is a standard PASGT with two features added: (1) An Ensolite™ 1/2-inch thick shock pad with an area of 20 in^2, and (2) a Velcro™* retention napestrap which improves helmet retention (Figure 1).

On 26 January 1983, USAARL submitted to the commander of XVIII Airborne Corps, Fort Bragg, North Carolina, its evaluation of the five fatal head injuries received during operation "Gallant Eagle" (USAARL, 26 Jan 83). The evaluation noted retention problems in the M-1 (all the fatalities lost their helmets) as well as the possibility that insufficient padding might have contributed to the degree of injury sustained in this operation. It further suggested energy-absorbing pads be added to the new PASGT helmet to reduce the impact force transmitted to the head to 150 G peak. The 150 G peak level was established through studies of head injuries in U.S. Army helicopter accidents.

In simplest terms, paratrooper operational "jumps" consist of three phases: The exit phase, the descent phase, and the landing phase. Before a jump, the airborne soldier has a prescribed checklist to follow before being considered ready. A jump master ensures each paratrooper has adhered to the proper prejump procedures.

While a unit is airborne, a jump master must extend his body outside the aircraft to assess for his troops the conditions of

the drop zone and surrounding aircraft. With air speeds in excess of 125 knots, coupled with engine blast, good helmet retention is a necessity. During the exit phase, the roll and pitch of the aircraft and variability of external air flow contribute to the incidence of the head striking the door frame and fuselage. Individuals also can be struck by the static line, deployment bag, or their personal equipment. During the descent phase, the opening shock of parachute inflation can cause forward rotation of the helmet, even with proper body orientation. Poor body orientation can cause the helmet to move rearward and/or sideward. The landing phase can be complicated by drop zone hazards such as trees, rocks, or equipment. Ground winds can cause pronounced swinging underneath the canopy, and landing with the wind can increase relative ground speed. Once on the ground, reinflation of the canopy can result in the soldier being dragged a considerable distance, especially if he is unconscious due to a prior head strike.

Parachute landing fall (PLF) training

When jumping with the standard T-10 parachute, one can expect the rate of descent to be 18 to 22 feet per second. To land safely, a parachutist must execute a proper PLF. The five recommended points of contact are progressively: Balls of the feet, lateral calf of the leg, thigh, buttocks, and "push up" muscle (the back of the upper arm) (Figure 2) according to the airborne training manual FM 57-220 (Departments of the Army and the Air Force, 1984). If the five points of contact do not absorb enough energy, and the head is not tucked with the chin against chest, head strike is likely to occur.

There are three basic PLFs: Front, side, and rear. Rearward drift is the most dangerous condition. Basic airborne training doctrine warns the parachutist to twist and "do the PLF you do best." Techniques for handling drift are refined on the lateral drift apparatus (LDA) (Figure 3). Techniques for handling the pronounced swinging under the canopy are refined using the swing landing trainer (SLT) (Figure 4). Because good techniques first must be learned, many trainees often repeatedly execute poor PLFs and, therefore, sustain head strikes. Cadre at the U.S. Army Airborne School are trained to note such occurrences and remove trainees from the training session after a given number of head strikes. The SLTs are surrounded by a sawdust pit to provide a relatively soft head strike surface. The sawdust frequently is raked to improve the energy-absorption properties. Figure 5 shows the placement of personnel at the SLT. The operational environment repeats the training scenarios for PLFs with the added hazards of rocky terrain and/or surface winds.

Materials and methods

Epidemiology

In order to determine the incidence of head injury in Army airborne operations, all DA Forms 285, "United States Army investigation accident reports," stored in the database at the U.S. Army Safety Center (USASC) at Fort Rucker, Alabama, were searched for the period 1 October 1984 to 30 September 1989. This time frame was chosen to limit the scope of this analysis to the last 5 complete years of data. Any case listed as an accident occurring during tactical parachute operations and resulting in an injury to the head was selected for inclusion in subsequent analysis. These reports were analyzed further for time of incident, circumstances surrounding the incident, presence of procedural errors, equipment failures, nature of the head injury, and information relating to the mechanism of injury.

Since there was no known source for information relating to the number of parachute deployments occurring over the period of study, no rate information could be calculated. In this study, we were only able to determine the total number of head injuries reported over the period and to tabulate the limited data contained in these reports.

Impact protection

A monorail drop tower (Figure 6) was used to assess the amount of force transmitted through the standard PASGT and modified PASGT helmets. Deceleration was measured with a uniaxial accelerometer mounted in the Z-axis of a standard headform in accordance with American National Standards Institute (ANSI) Z90.1, 1971. This medium-size, low-resonance magnesium alloy headform is approximately equal in mass and shape to that of a 50th percentile human head. The force was measured using a load plate consisting of three piezoelectric load washers between two triangular aluminum plates located under a flat, rigid steel impact surface. Graphs of deceleration versus time, and force versus time were kept for each drop by recording oscilloscope traces. Drop heights were varied to investigate the impact characteristics of the various configurations.

Peak deceleration was plotted against drop height for a rearward strike on five configurations of padding. The drop height varied from 12 to 42 inches. Because one does not always receive a blow directly to the rear of the head, the same procedure was repeated for a rear strike 45 degrees to one side (occipital-parietal region). Five helmet configurations were tested: (1) Standard PASGT helmet equipped with Ensolite™* shock pad and Velcro™* napestrap, (2) standard PASGT helmet shell with

a four-layer thermoplastic liner* (TPL™) and shock pad configuration provided by the Gentex Corporation, (3) standard PASGT helmet modified with adhesive 3/8-inch foam pads throughout the shell, (4) PASGT shell (without sling suspension) modified with Sensifoam™* (C-47) and TPL™ fitting pad, and (5) PASGT shell (without sling suspension) modified with Isofoam™* and a TPL™ fitting pad.

Helmet retention

The helmet retention test device used for simulating the forces encountered in opening shock and the execution of a poor rear PLF was a modified Department of Transportation (DOT) pendulum. A modified DOT Hybrid III headform* with articulated neck was attached to the pendulum arm (Figure 7). When released, the pendulum arm is allowed to free fall and strike an energy absorber which decelerates the pendulum arm at 24 to 28 peak G for a duration of approximately 40 milliseconds. These conditions are less severe than those imposed on a paratrooper's torso during the shock of an actual parachute opening. The peak deceleration is the same, but the pulse duration is 400 milliseconds in an actual opening shock (Call and Moynihan, 1978). The shorter duration pulse was selected since the test apparatus is not able to produce a longer duration pulse. Deceleration was measured by a uniaxial accelerometer mounted at the approximate T3 vertebra level.

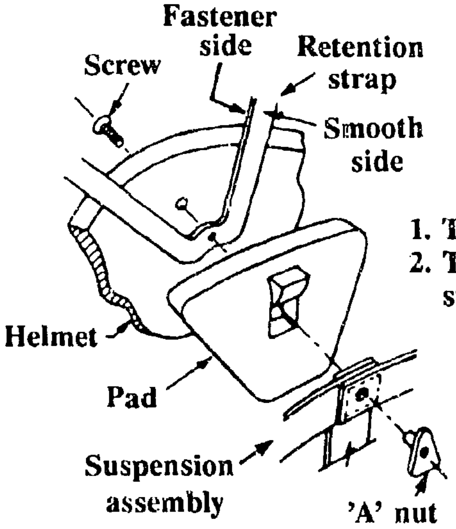
The entire deceleration sequence was recorded on a Spin Physics SP2000* motion analysis system (Figure 8). To follow the movement of the helmet relative to the headform, both were marked with targets. By using the reticle system and digitizing any two points on the helmet and headform, it was possible to record the change in relative angle between the two lines determined by the two sets of points (Figure 9). For forward impact simulating opening shock, the angles of interest were maximum forward movement and the subsequent rearward movement. In the rearward impact, simulating the execution of an improper rear PLF, the angles of interest were maximum rearward movement and the subsequent forward movement (Vyrnwy-Jones, Paschal, and Palmer, 1989).

Four different retention systems were tested on the PASGT helmet for airborne personnel. The standard retention system with shock pad and Velcro™ napestraps was tested in two arrangements (proper and improper). At a meeting at Fort Benning, Georgia, cadre stated airborne students were routing the napestraps through an upper loop formed in the chinstrap. Supposedly, this arrangement facilitated easy donning and doffing. Because this improper arrangement is commonly used, it was tested as well.

The third and fourth retention system configurations were standard PASGT shells containing a USAARL retention system prototype (shown with the standard retention system in Figure 10). This retention system differs from the currently used PASGT airborne helmet retention system in that the napestrap is mounted permanently to the right, helmet-mounted portion of the chinstrap and passes through a looped strap (keeper) which is mounted to the rear of the helmet. The free end of the napestrap is buckled to the left, helmet-mounted portion of the chinstrap. To ensure strength and reliability, no Velcro™ or snaps were used. The chinstrap was affixed to the helmet by two adjustable buckles (Figure 11). Chinstrap attachment points for the third configuration were the standard mounting points. The chinstrap attachment points for the fourth configuration were the forward mounting screws of the headband (Figure 12). This configuration caused the napestrap-to-chinstrap distance to increase, and, theoretically, increased stability. The napestrap keeper attachment point was lowered approximately 2 inches below the shell edge. This gave the napestrap a better grip on the head at the base of the skull (occipital condyles). The chinstrap was lengthened to compensate for the higher attachment points of configuration 4. Modifications were made from materials currently available in the U.S. Army inventory.

Parachutists

To jump with this helmet requires addditional items for your safety



1. The foam impact pad.
2. The parachutist's retention strap with 5/8" screw.

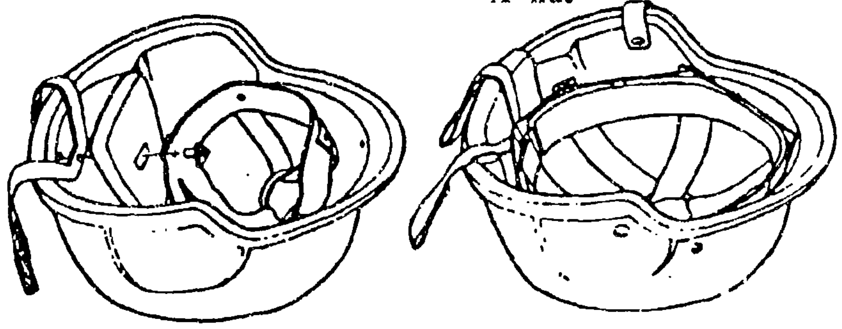


Figure 1. Installing shock pad.

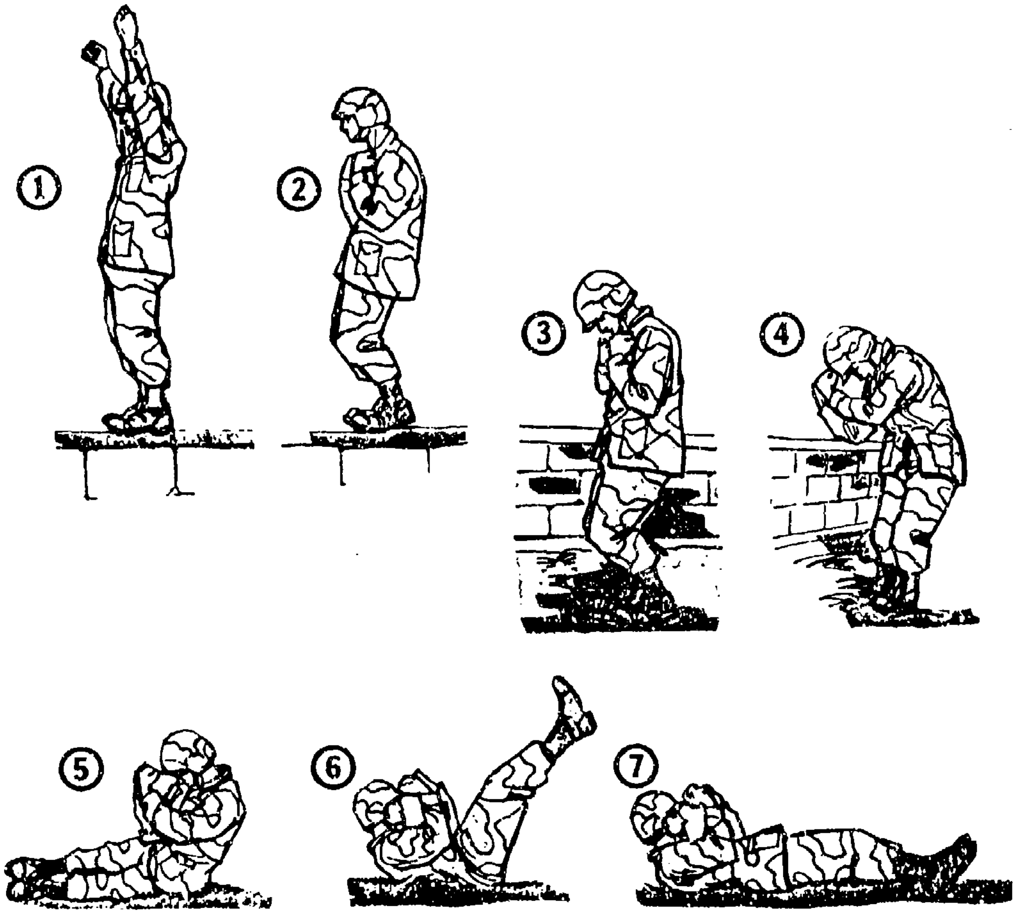


Figure 2. PLF sequence.

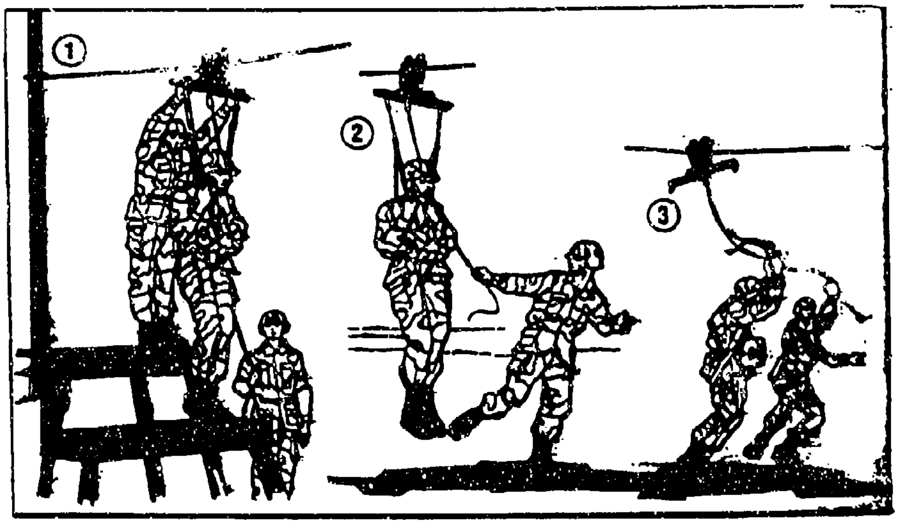


Figure 3. Correcting PLF problems.

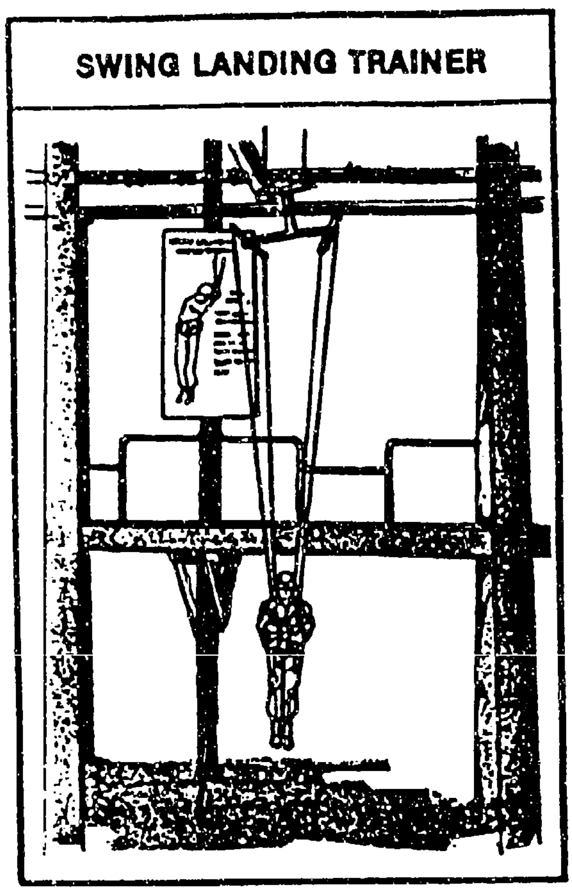
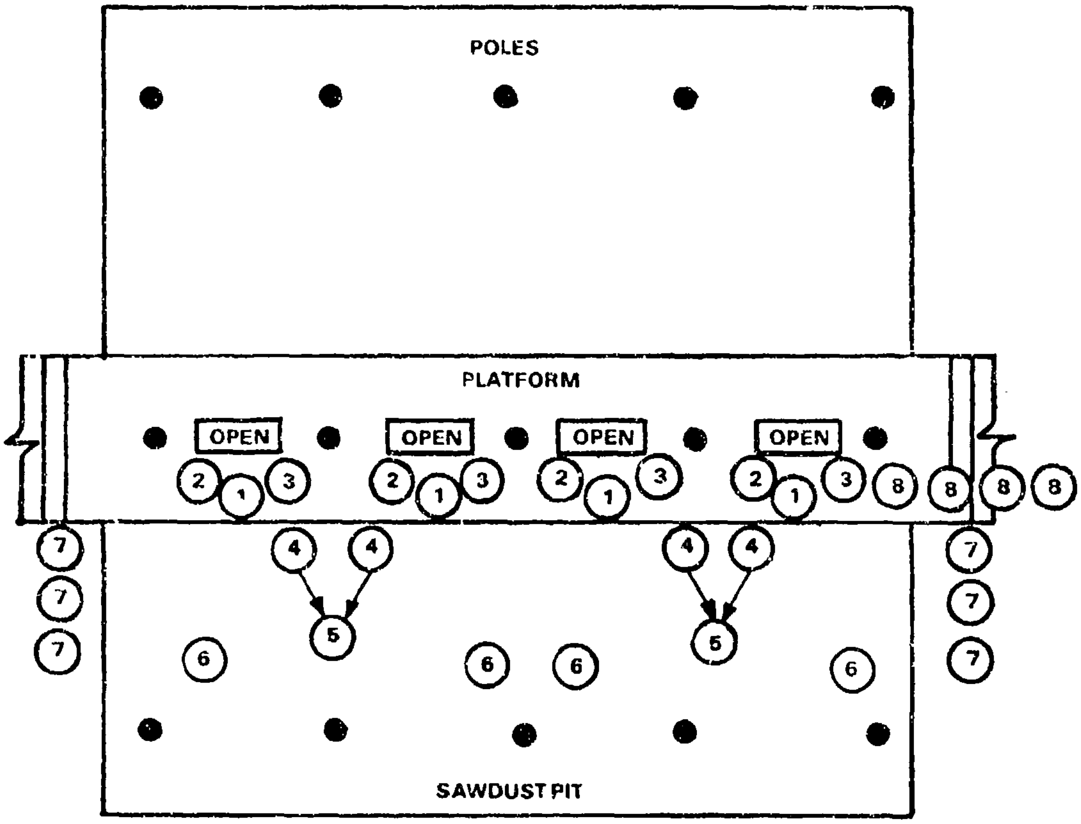


Figure 4. PLF training device.

PERSONNEL POSITIONING



LEGEND

(1) JUMPER	(5) INSTRUCTOR
(2) PLATFORM ROPEMAN	(6) UNHOOKMAN
(3) HOLDMAN	(7) STUDENTS OBSERVING
(4) PIT ROPEMAN	(8) STUDENTS PREPARING TO JUMP

SAFETY CONSIDERATIONS

- The landing area is constructed of sawdust or like material.
- The ropes used on the apparatus are checked daily for wear.
- Spreader bars and risers are checked for wear.
- Harnesses and canopy release assemblies are checked for completeness and serviceability.
- The student is not dropped more than 4 feet.
- The student is not dropped on the initial oscillation or when unprepared for the fall.
- The student is dropped at a point in oscillation which aids in executing the desired PLF.

Figure 5. Layout of Eubanks Field.

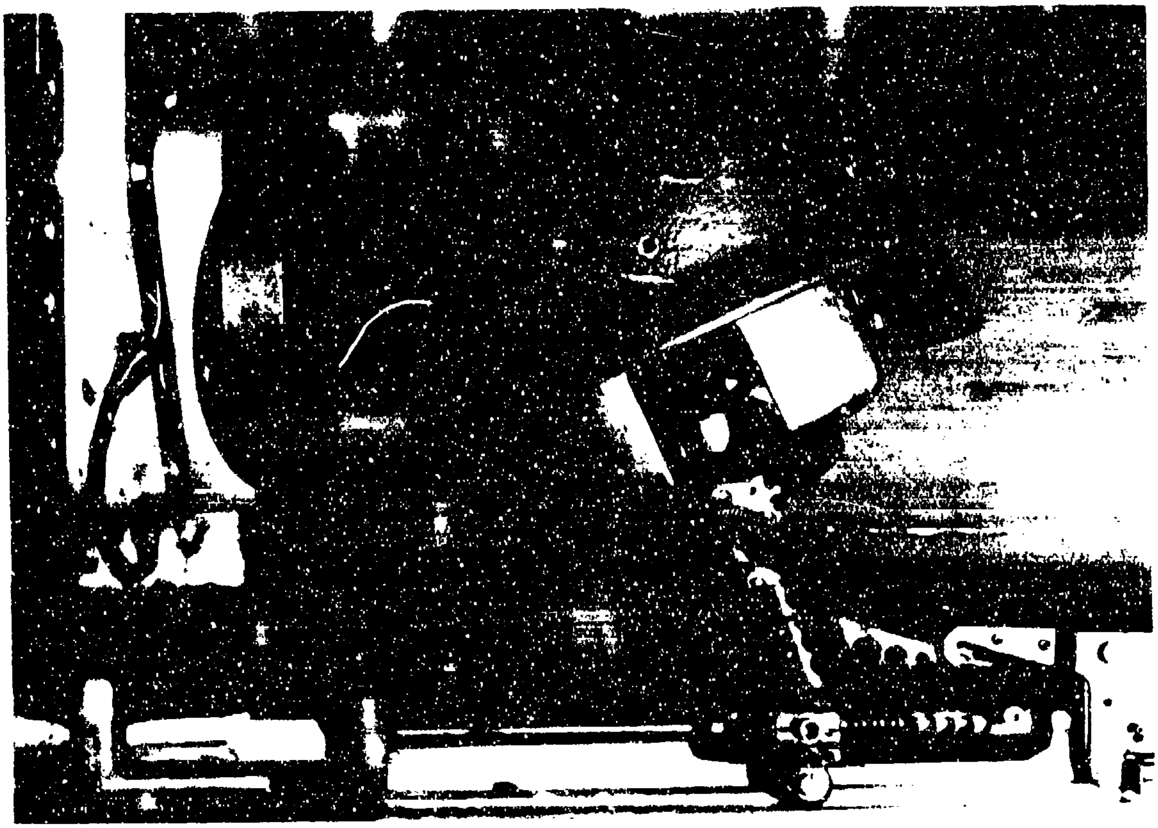


Figure 6. Drop tower.

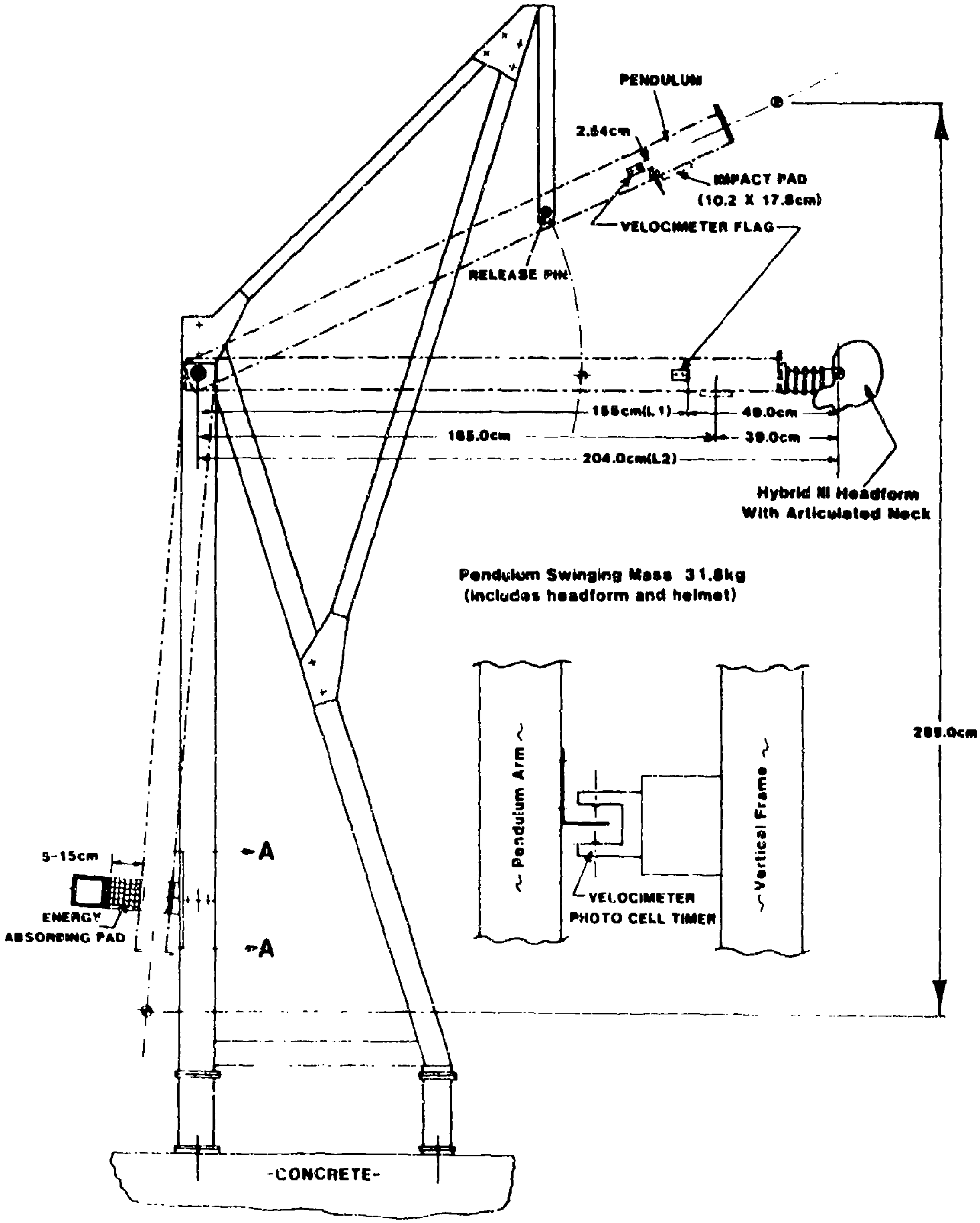


Figure 7. Swing tower.

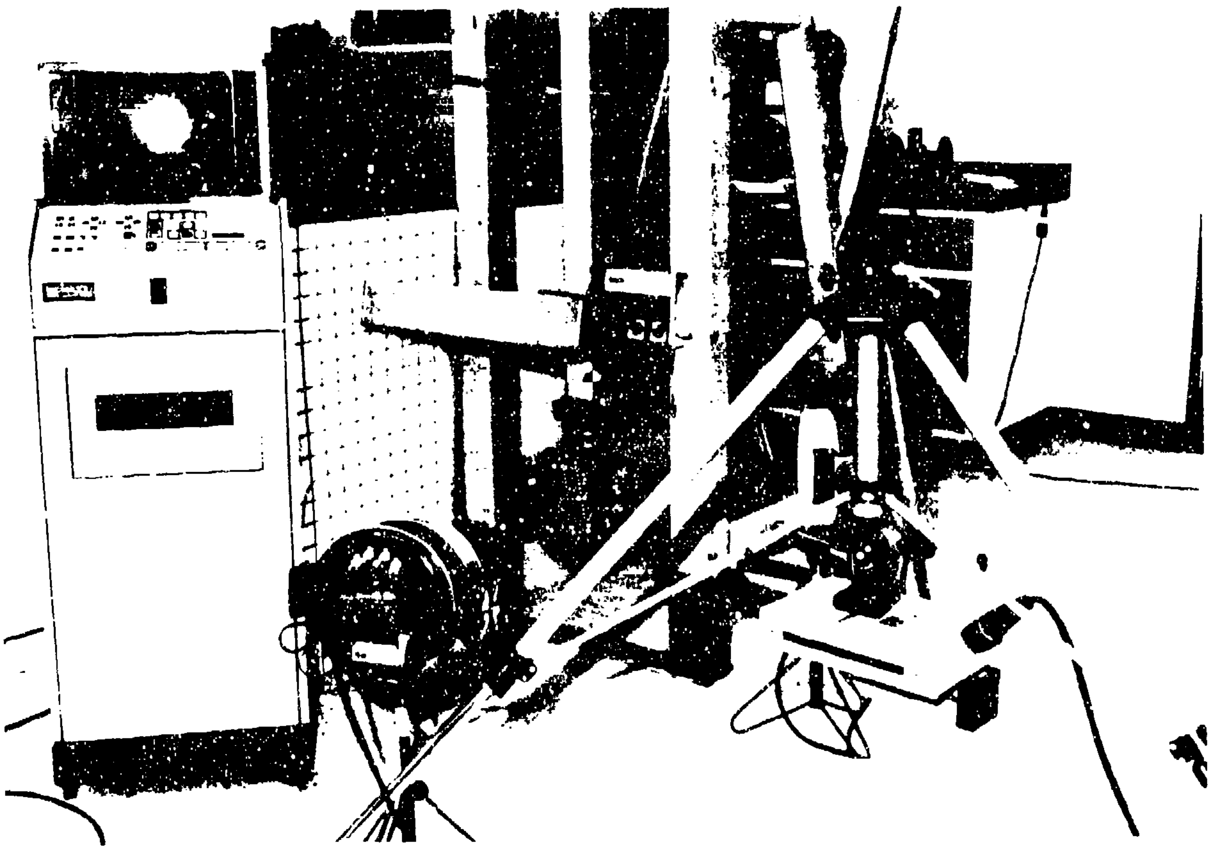
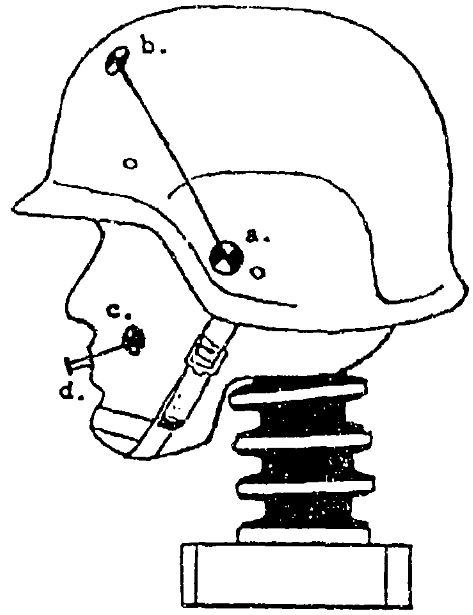
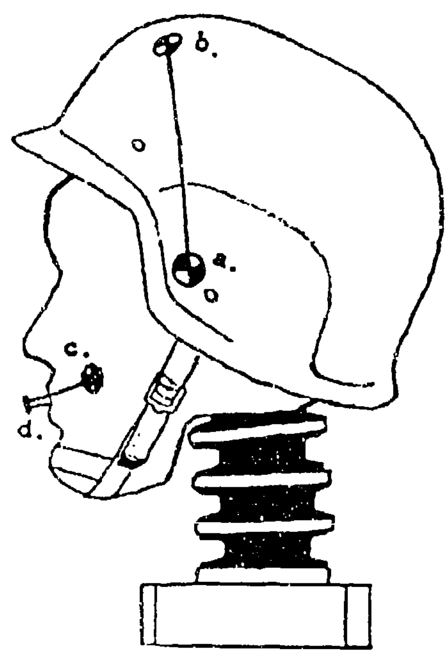


Figure 8. High speed video equipment.



Resting position showing digitized points.



Rearwards movement of helmet relative to headform showing digitized points.

Figure 9. Angles on PASGT.

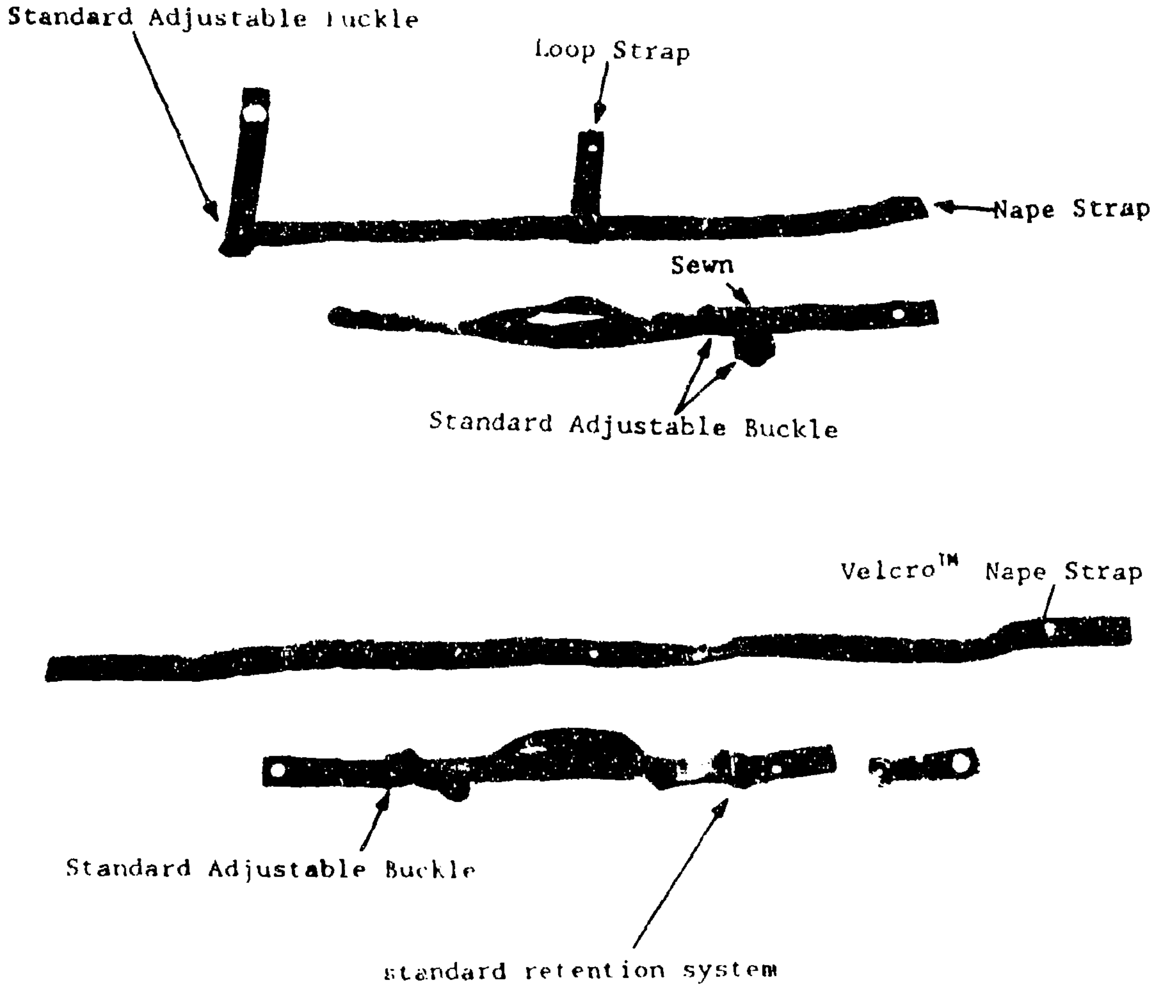


Figure 10. Standard and modified retention systems.

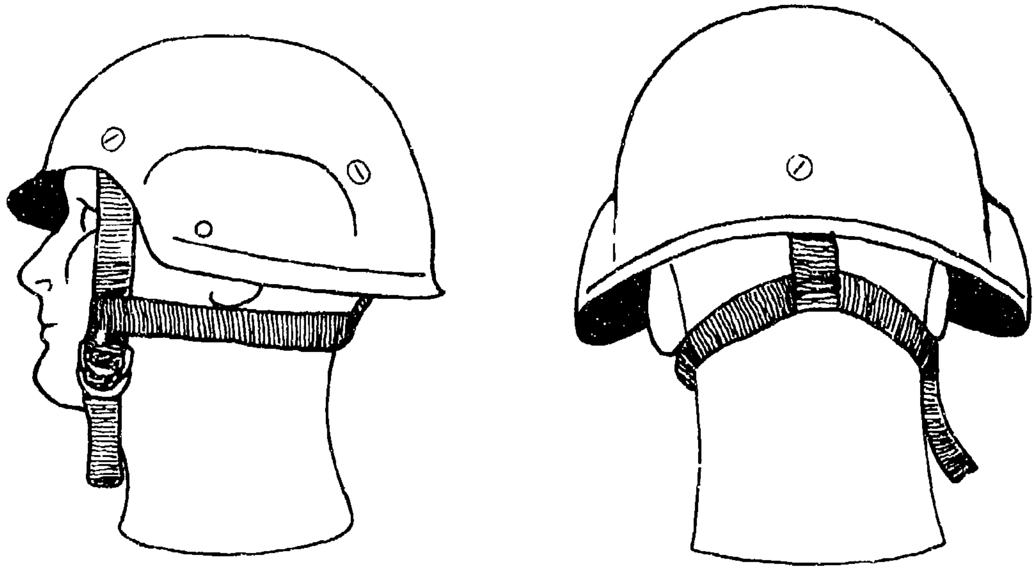


Figure 11. Forward-mounted modification of retention system.

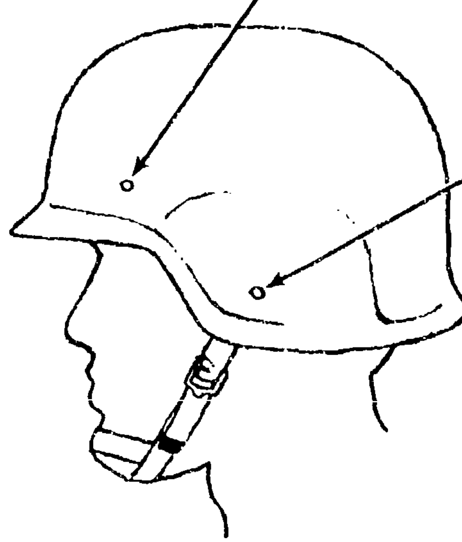


Figure 12. Side view of PASGT helmet.

Results

Epidemiology

Over the period of the study, fiscal years 1985 to 1989, there were 277 reports of individuals sustaining head injuries during U.S. Army airborne operations. There were 269 males and 8 females. Table 1 is a distribution of these cases by phase of parachute jump during which the injury occurred. Although most injuries occurred during the landing phase (77.8 percent), head injury was reported during all phases. The distribution of cases according to previous jump experience is shown in Figure 13. Note that relatively few head injuries occurred during initial airborne training (less than 6 jumps) except in ground training (0 jumps). Head injury appears to have a biphasic peak at 10 and 20 jumps, then declines slowly with additional experience. An age distribution of accident victims is shown in Figure 14. The mean age of victims was 22.8, with a range in age of 17 to 50.

The distribution of injury cases by time of day is shown in Table 2. Since exposure data is not available, it is difficult to draw any conclusions from these data except that head injuries appear to be evenly divided among night and day operations. Table 3 lists the surface impacted by the head injury victim when known and reported as a contributing factor. For the majority of cases, the impact surface was unknown or not reported.

Of the 277 individuals receiving head injury in airborne operations, only 4 sustained fatal injuries. The remainder were reported as lost workday cases. The locations and injury types sustained are shown in Tables 4 and 5. Over half of the injuries were intracranial (brain) and the majority of these resulted in loss of consciousness. The most commonly reported injury type was concussion (57 percent). Interestingly, head injury was the only reported injury for all but one of the cases. These data support the conclusion that head injury occurs as an isolated event in jumping accidents without injuries to other body areas.

Table 1.

Distribution of head injuries by phases of parachute operation.

Mishap type	Description	Frequency
Exit mishaps (7.6%)	Aircraft strikes (door/fuselage)	12
	Inverted jumper	4
	Equipment strikes	4
	Equipment failure	1
Descent mishaps (9.0%)	Maneuverability (twisted risers, etc.)	6
	Midair collision	11
	Helmet loss	4
	Opening shock equipment strike	3
	Collision with aircraft	1
Landing mishaps (77.6%)	Parachute landing fall	194
	Drag/reinflation	7
	Drop zone hazards (trees, etc)	14
Unknown (5.8%)	No description	16
Total		277

Table 2.

Distribution of head injuries by time of day.

Time	Frequency of injury	Percent of total injuries
Dawn	7	2.5
Day	134	48.4
Dusk	13	4.7
Night	123	44.4
Total	277	100.0

Table 3.

Distribution of head injuries by impact surface.

Impact surface	Frequency of injury
Drop zone obstacles (rocks, stumps, platforms, etc.)	18
Uneven terrain (ditches, ruts, mounds, etc.)	6
Ice/snow	2
Hard packed (landing strip, paved/unpaved roads, etc.)	13
Aircraft (door/fuselage)	12
Equipment strikes (static line, etc.)	4
Unknown	222
Total	277

Table 4.

Distribution of head injuries by injury location.

Location	Frequency of injury	Percent of total injuries
Head, unspecified	116	41.9
Brain	144	52.0
Skull	3	1.1
Facial	8	2.9
Eyes	2	0.7
Other	4	1.4
Total	277	100.0

Table 5.

Distribution of head injuries by injury type

Injury type	Frequency of injury	Percent of total injuries
Concussion	158	57.0
Fracture	10	3.6
Abrasion/contusion/ laceration	12	4.3
Miscellaneous	46	1.6
Unknown/ not reported	51	18.5
Total	277	100.0

Impact protection

Peak acceleration was plotted against drop height for a rearward strike for all five helmet configurations. Figures 15 and 16 show the Isofoam™ configuration to be superior. The Gentex Corporation prototype came in second, and the helmet modified with Sensifoam™ (C-47) was third for drop heights below 35 inches. However, the curve of the Gentex prototype bottomed out sooner, making the Sensifoam™ (C-47) superior above 35 inches. The standard PASGT helmet (includes Ensolite™ shock pad) modified with 0.38 inch adhesive Isofoam™ pads was only slightly better than the standard. The Ensolite™ shock pad for a rear impact protected to a drop height of 18 inches, while the addition of the 0.38 inch foam pad increased the protective level to only 21 inches, a 20 percent improvement.

Helmet retention

Table 6 shows the average rotation in degrees of the helmet on the headform during a rearward impact. The modified retention system reduced rearward movement of the helmet on the headform as compared to the standard PASGT paratrooper helmet. Also, Table 6 shows the standard PASGT helmet, when worn with the improper, but commonly used, napestrap arrangement, performs similarly to the properly worn standard PASGT helmet during the primary motion, but experiences greater rebound rotation. The no. 3 and no. 4 modified retention system configurations behave similarly during rearward impact.

Table 7 shows both standard PASGT paratrooper helmet's configurations exhibit very little forward rotation upon forward impact, although both showed significant rebound rotation. Also, Table 8 shows the modified retention system with standard chinstrap configuration rotated upon forward impact, but the rebound rotation was not as great as that of the standard PASGT. In summary, the data depicts the modified retention system with the forward mount to perform better than the modified standard mount and was exceptional compared to the standard PASGT configurations.

Table 6.

Change in angular rotation during rearward (eyeballs in) impact.

Helmet type	Initial rotation (degrees)	Rebound rotation (degrees)
Standard PASGT for paratroopers napestrap proper	36 rearward	7 rearward
Standard PASGT for paratroopers napestrap improper	36 rearward	11 forward
PASGT helmet USAARL retention system standard mounted	3 rearward	1 rearward
PASGT helmet USAARL retention system forward mounted	3 forward	0

Table 7.

Change in angular rotation during forward (eyeballs out) impact.

Helmet type	Initial rotation (degrees)	Rebound rotation (degrees)
Standard PASGT for paratroopers napestrap proper	1 rearward	38 rearward
Standard PASGT for paratroopers napestrap improper	0	33 rearward
PASGT helmet USAARL retention system standard mounted	15 rearward	20 rearward
PASGT helmet USAARL retention system forward mounted	4 forward	16 rearward

Discussion

Epidemiology

The analysis of paratrooper accident reports revealed there were 277 who sustained head injuries during airborne operations over the 5-year period of the study. Unfortunately, accurate exposure data could not be obtained to estimate the rate of head injuries. The rate of head injury is clearly quite low, but this fact should not detract from the military significance of these injuries. The objective of airborne operations is to deliver a concentration of force rapidly and clandestinely. Since the number of troops that can practically be delivered to an objective is usually limited, every soldier injured in the drop will have an adverse effect on mission accomplishment.

Head injury frequently is incapacitating for some period of time. Furthermore, for a variety of reasons, many soldiers receive injuries which are never officially reported on a DA 285. Consequently, the number of injuries reported in the USASC database probably is a very conservative estimate of the actual incidence of injury in the Army.

In summary, most head injury in airborne operations is occurring as a consequence of a single strike to a helmeted head, usually during the landing phase. The moderate severity of the injuries as well as the fact that they occur as isolated events, suggests that the prevention of these injuries can be practically achieved simply by adding a layer of energy-absorbing foam to the existing PASGT helmet. Improvements to the retention system also will prevent helmet rotation or loss, events which may expose the head to injury. Since most head injuries are incapacitating, we conclude that improved head impact protection should be provided to paratroopers.

Although not an objective of the study, it is appropriate to comment on airborne injury reporting procedures. The DA Form 285 is a general accident investigation form used by the USASC for ground vehicles and paratrooper accidents (Figure 17). It does not ask airdrop-specific questions and the information on this form was often incomplete; frequently, data was included only because it was thought to be a contributing factor.

When there is a malfunction in parachute equipment, either personnel or cargo, the airdrop unit must fill out DD Form 1748-2 Airdrop Malfunction Report (personnel-cargo) (Figure 18). This is an airdrop-specific form, and the information is useful for epidemiological studies of military parachuting. Information on type of aircraft, altitude, speed, and jumper position (blocks 4, 9, 10, and 16) characterize the exit phase. Paratrooper equipment, parachute types (main and reserve) (blocks 15, 16, and

17) characterize the descent phase and give an estimate of total suspended weight and sink rate. Drop zone location, elevation, surface winds, visibility (blocks 7, 11, 12, and 13) characterize the impact area with the exception of obstacles. Previous number of jumps (block 19) documents experience. In several instances, familiarity with this form caused individuals to report this information in the narrative portion of the DA 285. Based on the need for better documentation of paratrooper injuries, it is clear the data provided, in both DA 285 and DD 1748-2, should be made available at the USASC.

Impact protection

The parachutist's helmet consists of four basic elements. The shell provides ballistic protection, the webbing cradle suspends the helmet mass, the retention system stabilizes against excessive movement, and the nape pad reduces the forces transmitted through the shell to the back of the head. Three million PASGTs have been procured, so a redesign of the shell is not a viable short-term alternative for improving impact protection.

The increase in the number and severity of head injuries previously noted and the relative ease of providing increased impact protection leads to the conclusion that inexpensive modifications to the current PASGT helmet are necessary and feasible, and will provide substantially increased impact protection over the short-term. Long-term improvements may require a change in the basic shell configuration of the PASGT.

Our preliminary experiments have shown that improved energy-absorbent padding provides a significant reduction in the transmitted acceleration to the head. Since injury data reveal that impact occurs to all areas of the helmet, padding should be added to the helmet to provide 100 percent coverage in the headband region up to a point approximately 8 cm above the lower edge of the headband. Of course, the addition of padding in lieu of the "standoff" cradle eliminates ventilating air unless the padding is provided with channels and/or separated foam strips. A net "skull" cap with padding inserts could be used within a PASGT shell. Such a design exists as the insert to the Standard DH 132 tanker's helmet and it has been very effective (Figure 19). These standard Ensolite™ foam inserts have 2 mm dimpled surfaces to cause a slight standoff from the scalp. There is a matrix of 2 mm diameter holes on a 2.5 cm spacing in the foam to provide ventilation. A similar arrangement (with larger 8-10 mm diameter holes and outer surface dimples) would alleviate the ventilation problem. Further evaluation of a foam-filled nomex net "skull" cap, similar to the DH-132 design, should be considered before selecting a PASGT foam liner.

Head injury at the Airborne School presents a specific problem that should be considered separately from injury in operational units. At least one fatality and eight less severe head injuries occurred during the PLF phase (tower drop) of airborne training. Many of these injuries occurred as a result of repeated head impacts over an extended period. Changes in the standard operating procedure for repeated head strikes should be considered. Training personnel should receive training by a physician on early symptoms and signs of closed head injury and emphasis should be placed on removing students from training after any significant head strike. Any student receiving a significant strike or exhibiting early symptoms of head injury including headache should be evaluated by a physician before returning to training. Specific neck strengthening exercises also should be considered as part of the physical training at the Airborne School and in operational units. This would increase the soldier's ability to keep his chin on the chest with a probable decrease in the number of head strikes during PLF training. Cadre should be briefed on the importance of reporting all head strikes.

It also may be helpful to improve procedures for caring for the sawdust used in the landing "pits." The sawdust should be kept dry and turned frequently to provide maximum impact attenuation during training.

Undoubtedly, the best method of preventing head injury during initial training would be to provide students with a special impact protection helmet during the ground phase of their training. Since there is no requirement for ballistic protection during ground training, a training helmet, such as those used in civilian jump training, could be provided to students during the early phases of training when they are most at risk for suffering a head injury. This helmet could have a metal shell to match the weight of a PASGT, but be padded with a full inch of energy-absorbing foam to provide a high level of impact protection. One of the arguments against such a helmet is the stress on realistic training. Techniques in bayonet training are refined with pugil sticks and protective gear, and, along the same lines, PLF techniques should be refined with a foam-padded helmet to protect from repeated head strikes.

Helmet retention

Mounting the chinstrap to a forward position on the helmet shell reduced rotational displacement of the helmet on the head. The triangle formed by the forward mounting point, the chin-, and the napestrap of the modified retention system has a wider base and is more stable. The improvement in helmet stability with the forward chinstrap location is revealed more dramatically by an

forward chinstrap location is revealed more dramatically by an actual "wear and pull" test in which one compares the rotational movement of the existing paratrooper PASGT to the modified-nape PASGT by wearing and pulling upward on the lower edge of the helmet.

During the impact tests, the chinstrap adjustment buckle failed totally in three tests even though the chinstrap was not the object of the tests. A literature search showed these buckles have failed throughout their history (Morimoto, 1977). The bending of the center bars was due to inadequate strength and/or inadequate cross-sectional area. The cyclic nature of the loading also contributed to its failure. The strength of these buckles is only 85 lb (±5 lb) per buckle based on a pull test with two samples. It is obvious the strength of this buckle should be increased to ensure against PASGT helmet loss under asymmetric loading conditions which may occur when: (1) The risers strike and tend to pull the helmet off in a poorly executed exit, and (2) the risers and/or obstacles catch the bottom edge of the shell during reinflation after the PLF. The current strength is simply too low to withstand the asymmetric and/or inertial load applied.

The inertial loads on the chest during parachute opening shock can be as high as 35 G based on published U.S. Navy data (Naval Air Systems Command, 1976). Since the head is attached to the chest via the relatively flexible neck, there is a consensus among researchers that the acceleration response of the head to an input at the upper thoracic vertebra (T1) may be increased by a factor of 1.3 to 2.0. Thus, the expected ultimate inertial load of the head is 35 G (chest) X 2.0 dynamic factor X 3.5 lb PASGT mass = 245 lb. This is a lower value than the 300-lb value required for commercial motorcycle helmets but, usually, the paratrooper is not exposed to crash forces as great as those seen in motorcycle accidents. This is a reasonable value to consider for strength because the greater strength also will result in less elongation, and concomitantly less "lofting" away from the head due to the centrifugal force acting on the helmet during opening shock or a bad PLF in high winds. It is suggested a 250-lb strength requirement be used in future procurement specifications for paratrooper PASGT retention systems and existing understrength buckles be replaced. The extra strength provides a hedge against production strength variation and material degradation with time.

One other decrement in impact protection was noted in the impact tests. The rear headband attachment screw is a size no. 8 steel screw with a 9mm-diameter "pan" head which tends to compress the KEVLAR™ shell under the screw head and to drive the interior anchor nut into the magnesium headform. The "bottoming" of the screw anchor nut causes a high headform acceleration. If

infantryman), a serious laceration could occur. If the steel screw was replaced with a nylon screw, the transmitted force would be reduced by several orders of magnitude because the modulus of elasticity of nylon is only 1 percent that of steel. The tensile strength of a no. 8 nylon screw is approximately 250 lb; probably, this is an adequate value for this design.

Airborne School personnel have suggested the large mass of the helmet might cause forces which inhibit soldiers from tucking in their chins. This leads to a pronounced head strike. Reducing the mass of the helmet could have several benefits. Current molds for the PASGT helmet need not be changed to reduce shell weight by using fewer layers of tighter-weave Kevlar™, or equivalent material. Using a tighter-weave Kevlar™ (or other weight-reducing material) would preserve the ballistic protection provided by the helmet while reducing the weight. The extra 3 mm of space within the shell would allow more foam to be placed in the headband region of the helmet, increasing coverage in a critical area of the skull. This foam-padded helmet could be produced specifically for airborne troops in kit form.

Summary

This study has shown head injury in airborne paratrooper operations is occurring as a consequence of helmeted-head impact, usually during the landing phase. The relatively moderate nature of most of the injuries, as well as the fact they occur as isolated events, suggest the prevention of these injuries can be achieved practically by adding a layer of energy-absorbing foam to the PASGT helmet. Improvements to the retention system also will help prevent helmet loss and rotation of the helmet on the head which exposes the head to injury.

Conclusions

1. Head injury is a significant problem in airborne training and operations (more than 50 annually).

2. Analysis of the type and mechanism of head injuries sustained in airborne operations reveals they occur as isolated injuries and usually are not critical long-term injuries.

3. A larger area of the head should be protected with energy-absorbing foam.

4. The incorporation of greater coverage and more efficient padding to the current PASGT helmet, combined with improvements

4. The incorporation of greater coverage and more efficient padding to the current PASGT helmet, combined with improvements to the retention system, will reduce substantially head injury in Army parachute operations. The addition of 0.5-inch thick pac reduces the force transmitted to the head to 109 G (1200 lb) from 272 G (3000 lb) (60 percent) for a 2-foot drop onto a rigid steel plate.

5. Further testing is necessary to assess the ventilation problems associated with increasing the surface area covered by the foam.

6. The forward-mounted prototype retention system described in this report significantly reduces forward and rearward movement of the helmet.

7. The strength of the existing adjustment buckle is inadequate for the intended use.

8. The no. 8 steel screw attaching the headband at the rear of the helmet tends to drive the interior anchor nut into the headform and reveals a potential for wearer head laceration.

Recommendations

Training environment

1. A new training helmet should be used by students until they demonstrate the ability to perform a proper PLF. It should be energy-absorbing and allow the head to experience no more than 100 G peak when tested at a drop height of 5 feet against a flat, rigid impact surface. The mass of the helmet should be equal to that of the PASGT airborne helmet.

2. Symptoms and signs of head injury should be taught to all training supervisors and any student exhibiting symptoms should be immediately removed from training and evaluated by a physician.

3. Improved head strike reporting methods should be initiated.

4. The sawdust at the SLT site should be deep tilled and kept dry to provide maximum impact protection.

5. Increased emphasis on neck strengthening exercises should be considered for airborne personnel in training and in operational units.

Operational environment

1. Provide an energy-absorbing liner to the current PASGT helmet that covers the entire headband region up to a point approximately 8 cm above the lower edge of the sweatband. This liner should be capable of limiting the transmitted force to the head to less than 150 G for a 2.5-foot drop on a flat rigid surface.

2. Replace the existing retention system with an improved system able to provide retention at least equal to the forward-attachment system described in this report.

3. Replace the existing chinstrap adjustment buckle with a similar design of 125-lb minimum pull strength.

4. Improve airborne injury reporting methods by combining data from existing forms DA 285 and DD 1748-2.

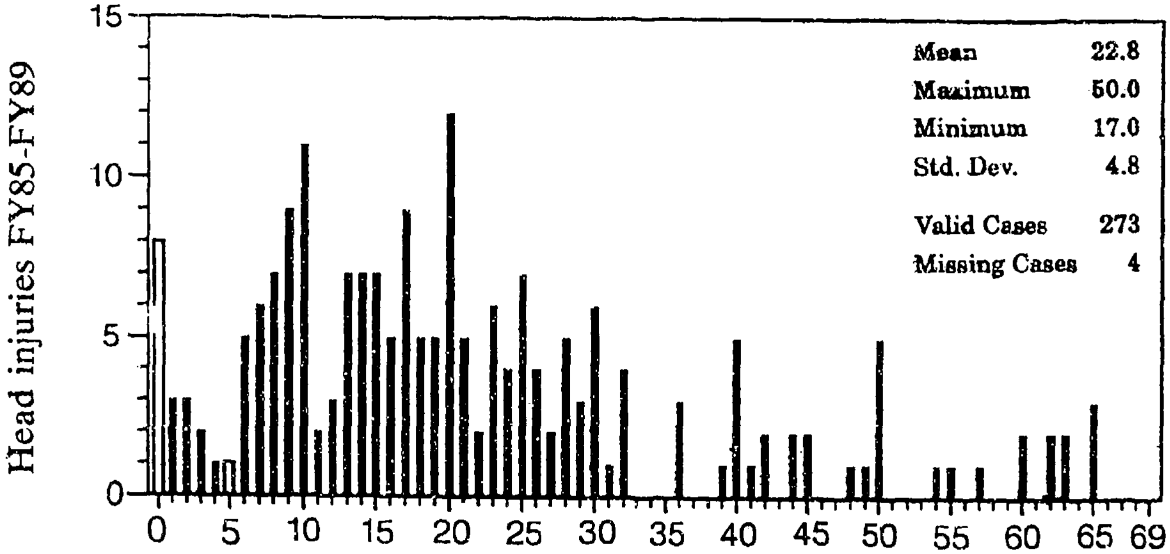


Figure 13. Previous parachuting experience.

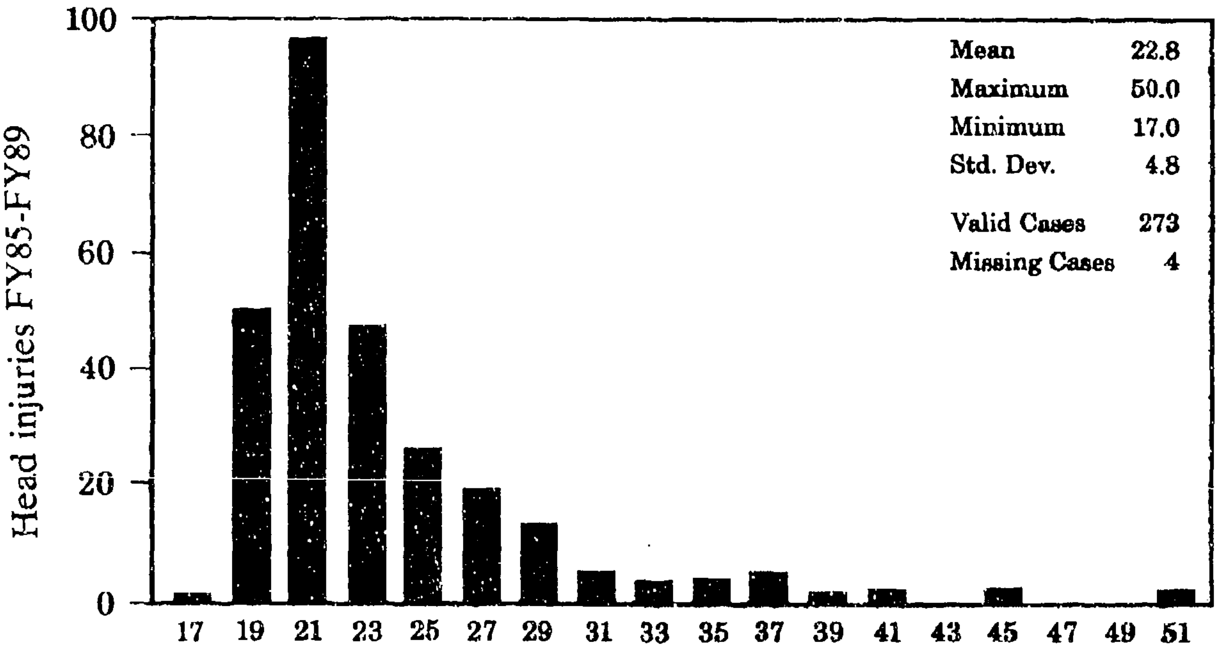


Figure 14. Age distribution.

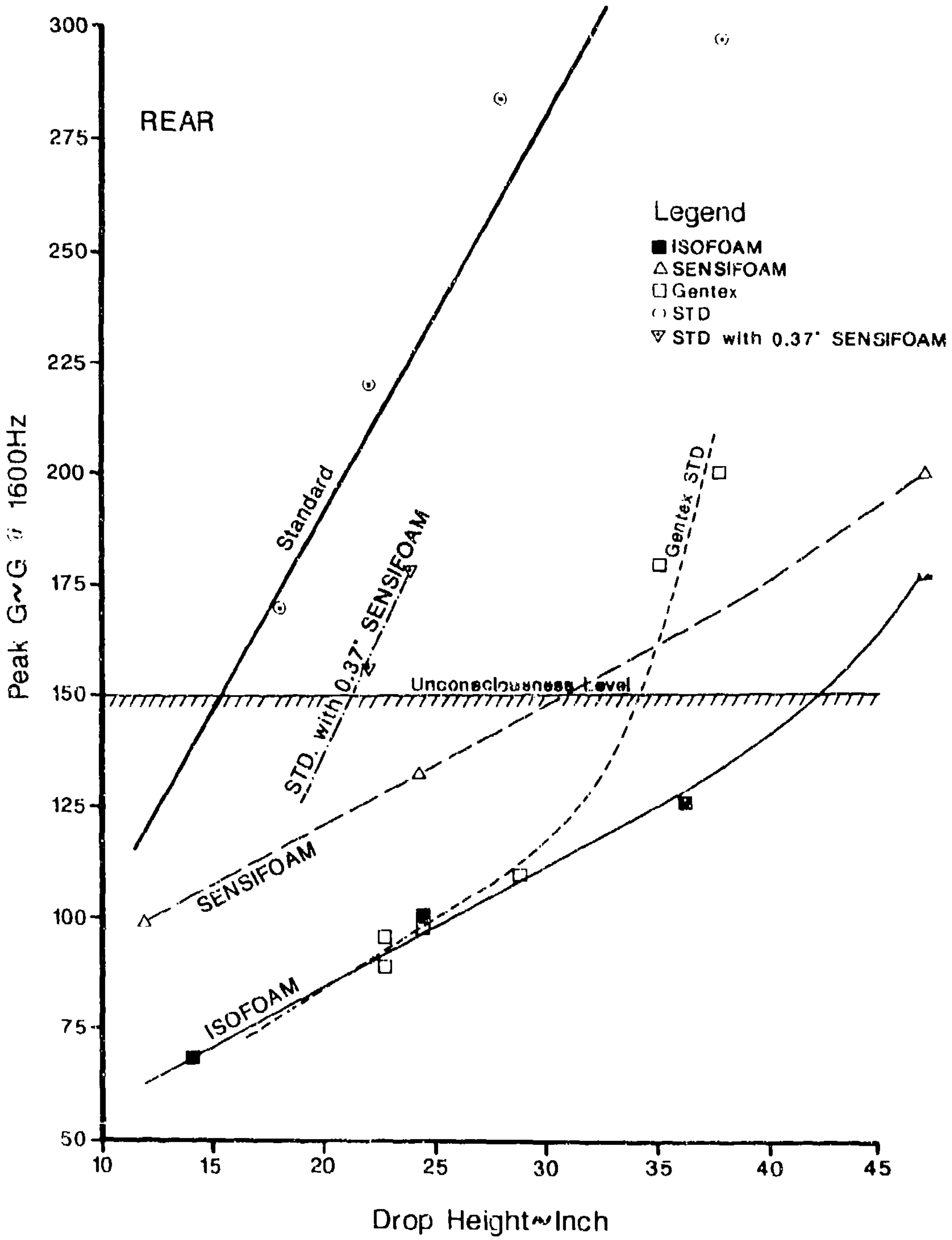


Figure 15. Peak G rear graph.

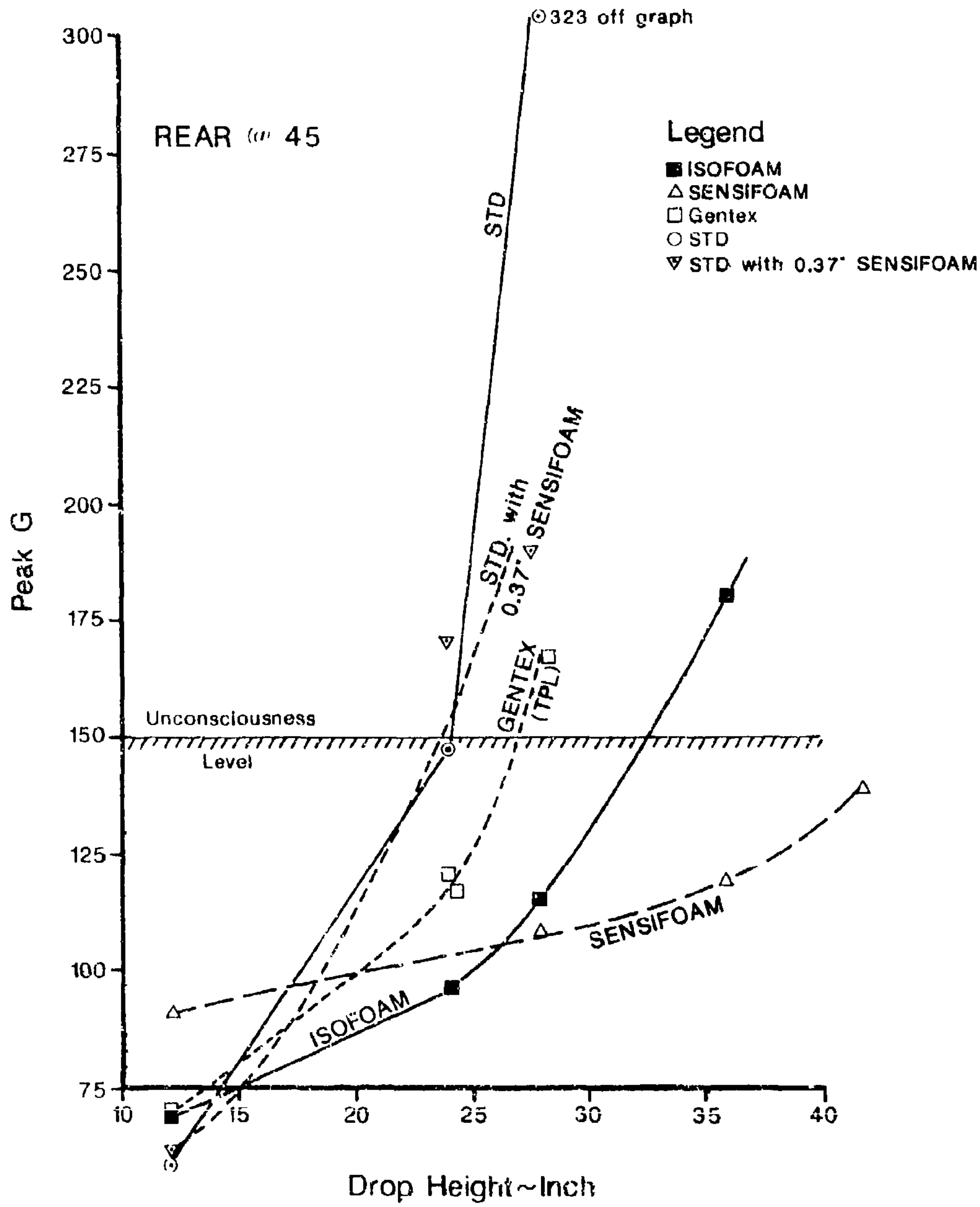


Figure 16. Peak G rear 45-degree graph.

UNITED STATES ARMY INVESTIGATION ACCIDENT REPORT

For use of this form, see AR 385-40; the proponent agency is DCSPER

NOTE: SPACES BELOW, DEFINED BY HEAVY LINES ARE FOR "SAFETY CENTER USE ONLY"

1. UNIT IDENTIFICATION — a. UIC; b. DESCRIPTION

2. TIME AND DATE OF ACCIDENT — a. YEAR; b. MONTH; c. DAY; d. HOUR

3. TIME OF DAY — a. DAWN; b. DAY; c. DUSK; d. NIGHT

4. LOCATION — a. ON POST; b. OFF POST

5. EXACT LOCATION OF ACCIDENT

SECTION A — PERSONNEL INVOLVED

6. NAME; 7. ADDRESS; 8. SOCIAL SECURITY NUMBER

9. GRADE; 10. AGE; 11. SEX (a. MALE; b. FEMALE); 12. MOS OR CIVILIAN JOB SERIES; 13. FLIGHT STATUS (a. YES; b. NO); 14. DUTY STATUS (a. ON DUTY; b. OFF DUTY)

17. CLASSIFICATION AT TIME OF ACCIDENT

a. ACTIVE ARMY; b. ARMY CIVILIAN; c. ARMY CONTRACTOR; d. NONAPPROPRIATED FUND; e. OTHER US MILITARY; f. ROTC; g. DEPENDENT

NATIONAL GUARD: a. TECH; b. IDT; c. AT; d. FTTD; e. FTM; f. ADT

ARMY RESERVE: a. IDT; b. AT; c. ADT; d. FTM

FOREIGN NATIONAL: a. DIRECT HIRE; b. CONTRACT HIRE; c. KATUSA

OTHER (Specify)

18. THIS PERSON'S ACTIVITY/TASK AT TIME OF ACCIDENT

19. IF THIS PERSON'S ACTIVITY WAS NECESSARY PART OF TRAINING, GIVE TYPE — a. BASIC (School); b. ADVANCED (School); c. PROFICIENCY (Unit); d. OTHER (Specify)

21. WAS THIS PERSON'S ACTIVITY PART OF TACTICAL TRAINING? — a. YES; b. NO

22. OPERATIONAL CATEGORY

23. SEVERITY OF INJURY TO THIS PERSON (Check only one)

a. FATAL; b. PERMANENT TOTAL DISABILITY; c. PERMANENT PARTIAL DISABILITY; d. LOST WORKDAY — DAYS FROM WORK; e. LOST WORKDAY CASE — RESTRICTED WORK ACTIVITY; f. NONFATAL CASE WITHOUT LOST WORKDAYS; g. FIRST AID ONLY; h. NO INJURY; i. MISSING AND PRESUMED DEAD

24. WORKDAYS LOST; 25. WORKDAYS RESTRICTED; 26. TYPE/NATURE OF INJURY/OCCUPATIONAL ILLNESS; 27. BODY PART AFFECTED

29. VEHICLE RESTRAINT SYSTEM — a. USED; b. NOT AVAILABLE; c. NOT APPLICABLE; d. AVAILABLE BUT NOT USED

SECTION B — PROPERTY AND/OR MATERIAL INVOLVED

NAME OF ITEM; OWNERSHIP; AMOUNT OF DAMAGE

SECTION C — ENVIRONMENTAL CONDITIONS INVOLVED

SECTION D — DESCRIPTION AND CORRECTIVE ACTION

ACTION TAKEN, ANTICIPATED, OR RECOMMENDED TO CORRECT THE CAUSE(S) OF THIS ACCIDENT

SIGNATURE OF COMMAND REPRESENTATIVE; COMMAND REVIEW

SAFETY STAFF USE ONLY

REPORT COMPLETION — a. INITIAL; b. CHANGE; MACOM; 41. LOCAL REPORT NUMBER; 42. ACCIDENT TYPE; 43. TYPE OF VEHICLE COLLISION

44. SAFETY STAFF POINT OF CONTACT; 45. SPECIAL REQUIREMENTS; 46. DATE REPORT COMPLETED

DA FORM 285 — EDITION OF 1 JUN 71 IS OBSOLETE

Figure 17. DA Form 285, U.S. Army Investigation Accident Report.

AIRDROP MALFUNCTION REPORT (PERSONNEL-CARGO)

INSTRUCTIONS

TO — Refer to Address in AFR 55-40, AR 59-4, OPNAVINST 4630 24, MCO 13480 1

FROM — Organization Submitting Report

Item 1 Enter actual designation and geographical location of military unit responsible for equipment that was airdropped (Example 612th Quartermaster Company, Fort Bragg NC)
Item 2 Show actual designation of the locality from which the unit being airlifted departed (Example Bravo LZ, Eglin AFB FL)
Item 3 Give day, month, and year that the form is prepared
Item 4 Indicate model and series of aircraft from which the malfunction occurred
Item 5 Give the complete serial number (tail number) of the aircraft from which the malfunction occurred
Item 6 Operation or exercise during which malfunction occurred if applicable
Item 7 Site at which airdrop occurred
Item 8 Date and time malfunction occurred
Item 9 Altitude of aircraft above the ground
Item 10 Aircraft speed at time of airdrop
Item 11 Actual elevation of drop/extraction zone
Item 12 Conditions at time of malfunction
Item 13 Same as for item 12
Item 14 Self explanatory
Item 15 List all equipment to include weapon
Item 16 Indicate position in stick and door exited
Item 17 Indicate the model/designation of the parachute which malfunctioned
Item 18 The following definitions apply

CIGARETTE ROLL – A type of malfunction occurring when a portion of the skirt of the canopy blows between two suspension lines and commences to roll with the opposite fabric. The heat generated by the friction of the fabric being rolled may cause the nylon to fuze

INVERSION—A type of malfunction occurring when a portion of the skirt of the canopy blows inward and between a pair of suspension lines on the opposite side of the parachute. This portion of the skirt forms a secondary lobe with the canopy inverted. The secondary lobe grows until the canopy turns completely inside-out

SEMI-INVERSION--Same as inversion except that formation of the secondary lobe stops before completely inverting

Item 19 Number of previous jumps made by the individual.
Items 20 and 21 Self-explanatory
Item 22 An injury is defined as requiring evacuation from the drop zone for medical treatment
Items 23 and 24 Self-explanatory
Item 25 If dual rail, show number of platforms loaded in the aircraft for airdrop. If CDS release gate, show number of containers loaded in the aircraft. If other, explain what type system was used
Items 26 through 29 Self-explanatory
Item 30 Indicate the sequential position of the malfunction load in the aircraft. For a three-platform load, the first load to be loaded will be load #3. The last platform to be loaded will be load #1
Item 31 This is the key in the report. Indicate all pertinent details. All factors which could contribute to the malfunction analysis should be given. Do not hide facts to save embarrassment. Photographs should accompany the report, when possible
Item 32 Unit's analysis of the causes of the malfunction. Lacking concrete proof, the professional opinion of those on the scene or involved, is solicited
Items 33 and 34 To be completed and signed by the individual who is knowledgeable of the facts contained in the report

TO	FROM

I. GENERAL

1 UNIT BEING AIRLIFTED	2 DEPARTURE AIRFIELD	3 DATE	4 TYPE ACFT	5 ACFT SER NO

6 OPERATION EXERCISE	7 DZ AND LOCATION	8 DATE AND TIME

9 ACFT ALTITUDE (Feet)	10 ACFT SPEED (Knots)	11 DZ ELEVATION (Feet)	12 SURFACE WINDS (Knots)	13 VISIBILITY (Feet/Miles)

II. PERSONNEL

14 NAME (Last, First, MI), GRADE, SSAN & UNIT	15 EQUIPMENT WORN BY JUMPER	16 JUMPER'S POSITION IN ACFT

17 TYPE PARACHUTE (Specify)

18 TYPE MALFUNCTION

SEMI INVERSION		INVERSION		CIGARETTE ROLL	OTHER (Specify)
PILOT CHUTE		BLOWN SECTION		BROKEN SUSPENSION LINE	

19 NO JUMPS

20 TYPE OF RESERVE	21 RESERVE FUNCTIONED PROPERLY (If "No" explain in item 31) [ ] YES [ ] NO	22 RESULTING INJURY

III. CARGO

23 TYPE LOAD AND WEIGHT	24 RIGGED IAW (TM/TO/NAVAIR No.)	25 AERIAL DELIVERY SYSTEM USED: DUAL RAIL / CDS RELEASE GATE / OTHER (Explain) / NO PLATFORMS / NO. CONTAINERS

26 TYPE PLATFORM/AIRDROP CONTAINER	27 TYPE PARACHUTE AND NUMBER	28 SIZE EXTRACTION/RELEASE PARACHUTE	29 LENGTH OF REEFING LINE	30 POSITION OF LOAD IN AIRCRAFT

IV. ANALYSIS

31 DESCRIPTION OF MALFUNCTION/FAILURE/DAMAGE INCURRED (If more space is needed, continue on reverse.)

32 CAUSE OF MALFUNCTION/FAILURE (If more space is needed, continue on reverse.)

33 TYPE OR PRINT NAME, GRADE, SSAN OF REPORTING OFFICER/AUTOVON NO. AND TELEPHONE EXTENSION	34 SIGNATURE

DD FORM 1 JUN 78 1748-2

Figure 18. DD Form 1748-2, Airdrop Malfunction Report (Personnel-Cargo).

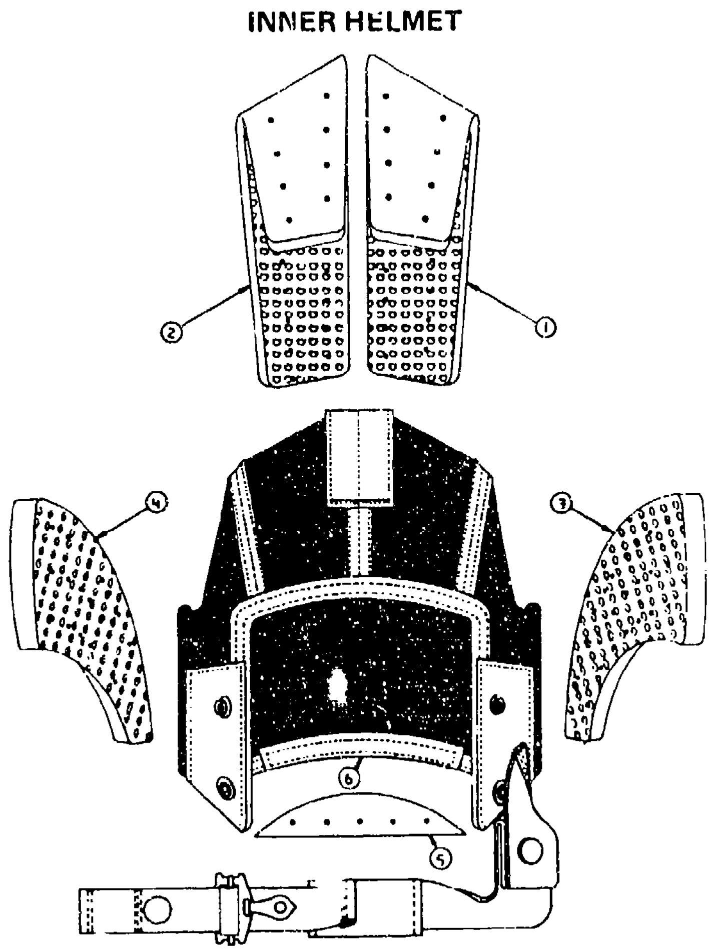


Figure 19. DH-132 insert.

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U.S. Army Infantry School, Fort Benning, GA. 19 October 89. Memorandum to Commander, U.S. Army Aeromedical Research Laboratory, Fort Rucker, AL. Subject: Prevention/reduction of head injuries to paratroopers during airborne training/ operations.

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Appendix A.

List of equipment manufacturers

Creative Foam Corporation
P.O. Box 238
55210 Rudy Road
Dowagine, MI 49047

Endevco
Rancho Viejo Road
San Juan Capistrano, CA 92675

General Motors Corporation
3044-T West Grand Boulevard
Detroit, MI 48202

Gentex Corporation
P.O. Box 315
Carbondale, PA 18407

GHI Systems
Randros Palos Verdes, CA

Humanoid System
Division of Humanetics Corporation
17022 Montanero Street
Carson, CA 90746

Kistler Instruments AAAG
Winterthur, Switzerland

Nicolet Instrument Corporation
Oscilloscope Division
5225 Verona Road
Madison, WI 53711

Spin Physics 2000, Kodak
3099 Science Park Road
San Diego, CA 92121-1011

The V-Tec Company
Hopewell, VA 23860

Tuscarora Plastics, Inc.
1830 Rockdale Industrial Blvd.
Conyers, GA 30207

Initial distribution

Commander
U.S. Army Natick Research
and Development Center
ATTN: Documents Librarian
Natick, MA 01760

Naval Submarine Medical
Research Laboratory
Medical Library, Naval Sub Base
Box 900
Groton, CT 06340

Commander/Director
U.S. Army Combat Surveillance
& Target Acquisition Lab
ATTN: DELCS-D
Fort Monmouth, NJ 07703-5304

Commander
10th Medical Laboratory
ATTN: Audiologist
APO New York 09180

Commander
Naval Air Development Center
Biophysics Lab
Code 60B1
Warminster, PA 18974

Naval Air Development Center
Technical Information Division
Technical Support Detachment
Warminster, PA 18974

Commanding Officer
Naval Medical Research
and Development Command
National Naval Medical Center
Bethesda, MD 20014

Under Secretary of Defense
for Research and Engineering
ATTN: Military Assistant
for Medical and Life Sciences
Washington, DC 20301

Commander
U.S. Army Research Institute
of Environmental Medicine
Natick, MA 01760

U.S. Army Avionics Research
and Development Activity
ATTN: SAVAA-P-TP
Fort Monmouth, NJ 07703-5401

U.S. Army Research and Development
Support Activity
Fort Monmouth, NJ 07703

Chief, Benet Weapons Laboratory
LCWSL, USA ARRADCOM
ATTN: DRDAR-LCB-TL
Watervliet Arsenal, NY 12189

Commander
Man-Machine Integration System
Code 602
Naval Air Development Center
Warminster, PA 18974

Commander
Naval Air Development Center
ATTN: Code 6021 (Mr. Brindle)
Warminster, PA 18974

Commanding Officer
Harry G. Armstrong Aerospace
Medical Research Laboratory
Wright-Patterson
Air Force Base, OH 45433

Director
Army Audiology and Speech Center
Walter Reed Army Medical Center
Washington, DC 20307-5001

Director
Walter Reed Army Institute
of Research
Wash.ngton, DC 20307-5100

HQ DA (DASG-PSP-0)
5109 Leesburg Pike
Falls Church, VA 22041-3258

Naval Research
Laboratory Library
Code 1433
Washington, DC 20375

Harry Diamond Laboratories
ATTN: Technical Information Branch
2800 Powder Mill Road
Adelphi, MD 20783-1197

U.S. Army Materiel Systems
Analysis Agency
ATTN: Reports Processing
Aberdeen proving Ground
MD 21005-5017

U.S. Army Ordnance Center
and School Library
Building 3071
Aberdeen Proving Ground,
MD 21005-5201

U.S. Army Environmental Hygiene
Agency
Building E2100
Aberdeen Proving Ground,
MD 21010

Technical Library
Chemical Research
and Development Center
Aberdeen Proving Ground,
MD 21010-5423

Commander
U.S. Army Institute
of Dental Research
Walter Reed Army Medical Center
Washington, DC 20307-5300

Naval Air Systems Command
Technical Air Library 950D
Rm 278, Jefferson Plaza II
Department of the Navy
Washington, DC 20361

Naval Research Laboratory Library
Shock and Vibration Information Center, Code 5804
Washington, DC 20375

Director
U.S. Army Human Engineering Laboratory
ATTN: Technical Library
Aberdeen Proving Ground,
MD 21005-5001

Commander
U.S. Army Test
and Evaluation Command
ATTN: AMSTE-AD-H
Aberdeen Proving Ground,
MD 21005-5055

Director
U.S. Army Ballistic
Research Laboratory
ATTN: DRXBR-OD-ST Tech Reports
Aberdeen Proving Ground,
MD 21005-5066

Commander
U.S. Army Medical Research
Institute of Chemical Defense
ATTN: SGRD-UV-AO
Aberdeen Proving Ground,
MD 21010-5425

Commander
U.S. Army Medical Research
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